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# Research to the Wear and Geometric Error Relations of Electro hydraulic Servo Valve

Huang xin Bi [a], Jin yong Yao [b], Yuan Li [a,b,] a*

[a] bihuangxin@163.com, bei hang university, Bei jing 100191,China
[b] jinyongyao@buaa.edu.cn, bei hang university, Bei jing 100191,China

**Abstract**

The working principle, failure modes and failure causes of the jet pipe servo valve has been analyzed. Get the main failure modes of the servo valve, which is caused by wear. The influences of the arris edge geometric error on the performance of the servo valve been analyzed. Get the wearing capacity equal to the edge arris geometric error. It provides an estimation method of the arris edge geometric error, which could be use to analysis the wearing capacity of the servo valve.

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*Key words:* jet pipe servo valve， spool valve, edge geometric error ,fillet radius, radial clearance

## 1. Servo Valve Working Principle

A jet pipe servo valve consists of two main assemblies, a torque motor assembly representing the first stage and the valve assembly representing the second stage. In-between the first and the second stages, there is a mechanical feedback connected to the spool and jet pipe to stabilize the valve operation. The jet pipe serves to convert pressure energy of the fluid into the kinetic energy of a jet and directs this jet towards the receiver block where it kinetic energy of the fluid into the kinetic energy of a jet and directs this jet towards the receiver block where its kinetic energy is recovered in the form of energy. The valve operates as follows[1]:

- At first stage null, the jet is direct exactly between the two receivers, making the pressures on both sides of the spool equal. The force balance created by equal pressures in both end chambers holds the spool in a stationary position.

* Corresponding author. Tel.: 13522008818.
*E-mail address: bihuangxin@163.com.*


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- The first stage torque motor receives an electrical signal applied as current to the coils, and is converted into a mechanical torque on armature and jet pipe assembly.
- As the jet pipe and armature rotate around the pivot point of thin walled flexure tube, the fluid jet is directed to one of the two receiver holes in the receiver block, creating a higher pressure in the spool in opposite direction to the jet pipe displacement.
- As the spool starts moving, it pushes the feedback spring, creating the torque on the jet pipe to bring it back to null position. When the restoring torque due to spool movement equals the applied torque balance is said to be steady state operation of the servo valve. The resulting spool position opens a specified flow passage at the ports of the second stage of the valve.

## 2. Jet Pipe Servo valve Failure Mode

The typical failure modes, failure causes and failure influence of the jet pipe servo valve is shown in Table1.

Table 1 jet pipe servo valve typical failure modes

| Project | Failure Mode | Failure Cause | Failure Influence |
|---|---|---|---|
| torque motor | Aprons rupture | The apron of the torque motor is not properly installed or defective | Excessive leakage in zero |
| | Motor failure | Spring tube rupture or failure | Flow is not bound, but each direction to obtain maximum flow |
| | | torque motor rupture | Flow is not bound, but each direction to obtain maximum flow |
| | zero offset | Torque motor or feedback spring was biased or washed by pressure | Servo valve performance degradation |
| | | Nozzle blocked | Servo valve performance degradation |
| | Pollution failure | Pollutants jam jet disk | Servo valve gain and the maximum flow reduction |
| Oil filter | Filter screen jam | Pollutants gathered | Flow area inadequate, Servo valve control pressure low |
| | Apron damaged | Aprons installation improper or defective | Servo valves equipped with oil spilling |
| Slide amplification stage | Clamping stagnation | Valve core jam in a position | Waveform distortion, jammed |
| | Edge wear | wear | increase leak and liquid noise, system zero offset increase |
| | Radial valve core wear | wear | increase leak and zero offset , lower gain |

We can see from the table, the main failure caused by wear of the servo valve is that the failure caused by edge wear and by radial valve wear. Therefore, we mainly study the edge wear and radial valve core wear.

## 3. The Relationship Between Spool Valve Wear And Arris Edge Geometric Error

The static performance index of servo valve includes flow gain, pressure gain, degree of asymmetry, hysteresis, resolution and static current consumption .Spool valve only have influence on flow gain, pressure gain, nonlinearity and static current consumption of the servo valve, but have no influence on other performance index.

Edge geometric error of the spool valve orifices mainly including the working arris-edge fillet of valve spool's, arris-edge non-verticalness errors of the valve spool, coplanarity errors of valve pocket's quadrate orifice and so on.

### *3.1. Radial clearance to spool valve performance influence*

Assuming valve core and valve set are ideal, only exist radial clearance. Then, the flow through the spool valve that is made up of the flow through the valve orifices and the leakage flow caused by the radial clearance. The flow characteristics of the spool valve is point to the relationship between the openings and the flow through the spool valve. The spool valve model as shown in Figure 1. Let radial clearance $\Delta_0 = (D - d)/2$

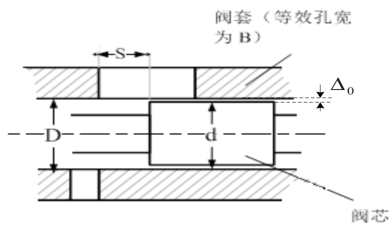


Figure 1 the spool valve model of only exist radial clearance

We can get (the flow through the valve orifices) is

$$Q_1 = C_d A\sqrt{2(p_1 - p_2)/\rho} = K\sqrt{S^2 + \Delta_0^2} \qquad (1)$$

In type：$C_d$: flow coefficient，0.60—0.70.，for the slide valve, the recommended value is 0.68.

A: open area of the choke， $A = B\sqrt{S^2 + \Delta_0^2}$；

B: the width of the choke，$B = D\arcsin(b/D)$，b is the width of the rectangular window of the valve set ,D is the valve core diameter.

S: The size of the slide valve opening amount.

ρ: liquid density.

$p_1$: oil pressure,;

$p_2$: return oil pressure.

K: $K = C_d B\sqrt{2(p_1 - p_2)/\rho}$ .

Then, the leakage flow caused by the radial clearance is concentric annular gap flow.Let the ring radius r, when $\frac{\Delta_0}{r} \leq 1$ ,the flow is

$$Q_2 = \frac{\pi d \Delta_0^3 \Delta p}{12\eta l} \qquad (2)$$

In type：d: valve core diameter.

$\Delta p$: pressure difference on both sides of the gap.

$\nu$ : kinematic viscosity of liquid.

$l$ : gap length.

The flow characteristic curve as shown in Figure 2.

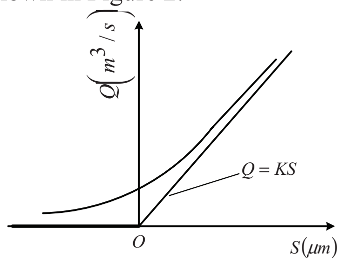


Figure 2 flow characteristic curve of only exist radial clearance

Radial clearance has a direct effect on the performance of the valve. If the gap is too small that could easily lead to action not flexible of the slide valve, even cause stuck and cause serious trouble. Excessive radial clearance is direct impact on static consumption flow index. At the same time, the Radial clearance also caused a non-linearity in the small open areas, affect the flow gain value.

*3.2. The working arris-edge fillet of valve spool to spool valve performance influence*

Assuming valve core and valve set are ideal, only exist the working arris-edge fillet. Set fillet radius r. The spool valve model as shown in Figure 3.

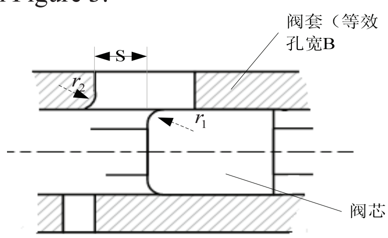


Figure 3 the spool valve model of only exist working arris-edge fillet

We can get the spool valve flow is

$$Q = C_d A \sqrt{2(p_1 - p_2)/\rho} = K\left(\sqrt{r^2 + (r+s)^2} - r\right) \tag{3}$$

Flow characteristic curve set Q=KS as the asymptote. As shown in Figure 4.

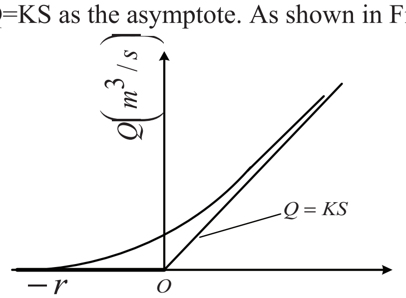


Figure 4 flow characteristic curve of only exist working arris-edge fillet

The figure shows, the working arris-edge fillet of the valve core have a obvious influence on spool valve performance. Seriously affecting the flow characteristic curve in small open area, reduce flow gain, increase the valve's non-linearity, increase quantity of leakage In the zero position and quantity of inner leakage.

*3.3. Summary*

Known in Section 2, during the using course, the spool valve mainly happens edge wear and radial valve core wear. With the slide valve wear increases, the flow gain lower, the nonlinear degree increase, the quantity of leakage increase. The edge wear have on the working arris-edge fillet of valve spool, the radial valve core wear have influence on the radial clearance between valve core and valve set. Conclusion from the analysis, the radial clearance and the working arris-edge fillet are also affected the the flow gain , the nonlinear degree and the quantity of leakage of the spool valve .Therefore, we can through analysis of the influence of Edge geometric error of the spool valve orifices to the spool valve performance to analysis the influence of spool valve wear.

## 4. Estimated Fillet Radius And Radial Clearance

A spool valve consisting of valve core and valve set is equivalent to a nozzle cap wrench agencies (Figure 5).There are many geometric error in the practical model. Only the radial clearance and the fillet radius is the major cause the caused the valve's non-linearity.

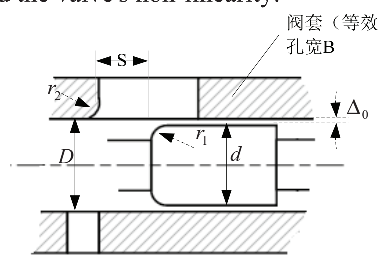


Figure 5 the nozzle cap pull bodies

Only consider he radial clearance and the fillet radius ,set a average of the fillet radius of each point $R_1$ , $R_2$ , . The mathematical model of flow displacement curve is

$$Q = \begin{cases} KB\left[\sqrt{(R+\Delta)^2 + (R+s-s_0)^2} - R\right] \\ KB\Delta \end{cases} \tag{4}$$

In type : $R = R_1 + R_2$

The actual flow curve and the flow displacement curve as shown in Figure 6. Using the theoretical formula Fitting to estimate the fillet radius and the radial clearance.

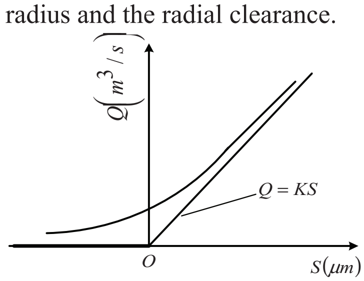

Figure 5 the actual flow curve and the flow displacement curve

Assuming have been measured a sets of data between m and n.

$$\hat{Q}_i \sim s_i\left(i = 1, \cdots, N\right)$$

Set $KB = a_1$, $R = a_2$, $\Delta = a_3$, $s_0 = a_4$, ,we can get

$$Q = \begin{cases} a_1\left[\sqrt{(a_2 + a_3)^2 + (a_2 + s - a_4)^2} - a_2\right] & s > a_4 - a_2 \\ a_1 \cdot a_3 & s \le a_4 - a_2 \end{cases} \tag{5}$$
$$= f\left(s, a_1, a_2, a_3, a_4\right)$$

Using the theoretical formula Fitting ,we can get

$$\begin{cases} \sum_{i=1}^{N} a_{kj}\Delta_j = a_k^{(0)} & (k, j = 1,2,3,4) \\ a_{kj} = \sum_{i=1}^{N} \frac{\partial f_{i0}}{\partial a_k} \cdot \frac{\partial f_{i0}}{\partial a_j} & (k, j = 1,2,3,4) \\ a_k^{(0)} = \sum_{i=1}^{N} \frac{\partial f_{i0}}{\partial a_k}\left[\hat{Q}_i - f_{i0}\right] & (k, j = 1,2,3,4) \end{cases} \tag{6}$$

Using the above formula,we can get the the fillet radius and the radial clearance..

## 5. Conclusion

By analyzing the electro-hydraulic servo valves, we can know the spool valve is the major part of the servo valves that Malfunction caused of wear.Through analysis the influence of the edge geometric error of the spool valve orifices to the spool valve performance .we can get the influence of the spool valve wear to the spool valve performance .At the same time,Using the formula to estimate the fillet radius and the radial clearance get the abrasion loss of the spool valve.

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